eRHIC e-/e+ Ring & Injector

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- Status / Open Questions
- 5-10 GeV Ring (Design Goals/Strategy/Comparison w/ other facilities)
- 10 GeV electron/positron injector
- Ring Polarization Handling/Design
- Lepton Ring Path Length Adjustment
- Beam Instabilities - Comparison w/ existing facilites
- Preliminary Cost Considerations
- Operational Mode – An Open Question
- Summary

Status: April 2004

- The BNL/Bates/DESY/BNP team has developed an eRHIC Zero Order Design (ZDR) (Hard Copies Available)
- This achieves a luminosity of 0.44×10^{33} using conservative limits on:
  - -Beam beam tune shift
  - -Synchrotron Radiation Heating
  - -Beam emittance aspect ratio and focusing through IP

using existing technologies for:

  - -Polarized electron source
  - -10 GeV injection accelerator
  - -e-/e+ storage ring

Open Questions/Action Items

Action Items for continuing eRHIC design effort:

- -Layout on BNL site
- -Interference/clearance w/ RHIC rings
- -Path length adjustment for varying hadron energies
- -Continuing evaluation/simulation of equilibrium polarization due to alignment tolerances and magnetic errors
- -Integrate downstream spin rotator w/ longitudinal Compton Polarimeter
- -Compare merits of different injector architectures – eRHIC operation
- -Positron production, accleration and capture
  - e-/e+ ring dynamic aperture
- -Develop polarized photoinjector satisfying eRHIC requirements
- -Refine cost models for eRHIC accelerator and rings

eRHIC e-/e+ Ring Design Goals

Peak luminosity for 10 GeV e on 250 GeV p	10^{32} - 10^{33} $cm^{-2}s^{-1}$
Longitudinal polarization	> 70% at IP
Average current	0.45 Amp
Electrons per bunch	10^{11}
Number of electron bunches (simple harmonic of RHIC)	120
Energy range	5 – 10 GeV
Positron (electron) radiative polarization time	20 minutes @ 10 GeV 10 Hours @ 5 GeV

Distinguishing features of eRHIC-e

Comparison to existing lepton rings

	HERA-e	***B-Fac***	***eRHIC-e***
Energy (GeV)	*~ 27*	*~3(L), ~9(H)*	*5 - 10*
Current (A)	*0.05*	*1.0 – 2.5*	*0.45 – 1.0*
Polarization	*Yes*	*No*	*Yes*
BB para.	*~0.05*	*~0.08*	*0.08*

eRHIC-e: a combination of

- wide operating energy range
- high intensity, though not extremely high
- strong-strong BB regime
- longitudinal polarization

Electron/Positron Ring Strategy

F. Wang

<u>Goals: Maximum luminosity and maximum polarization</u>

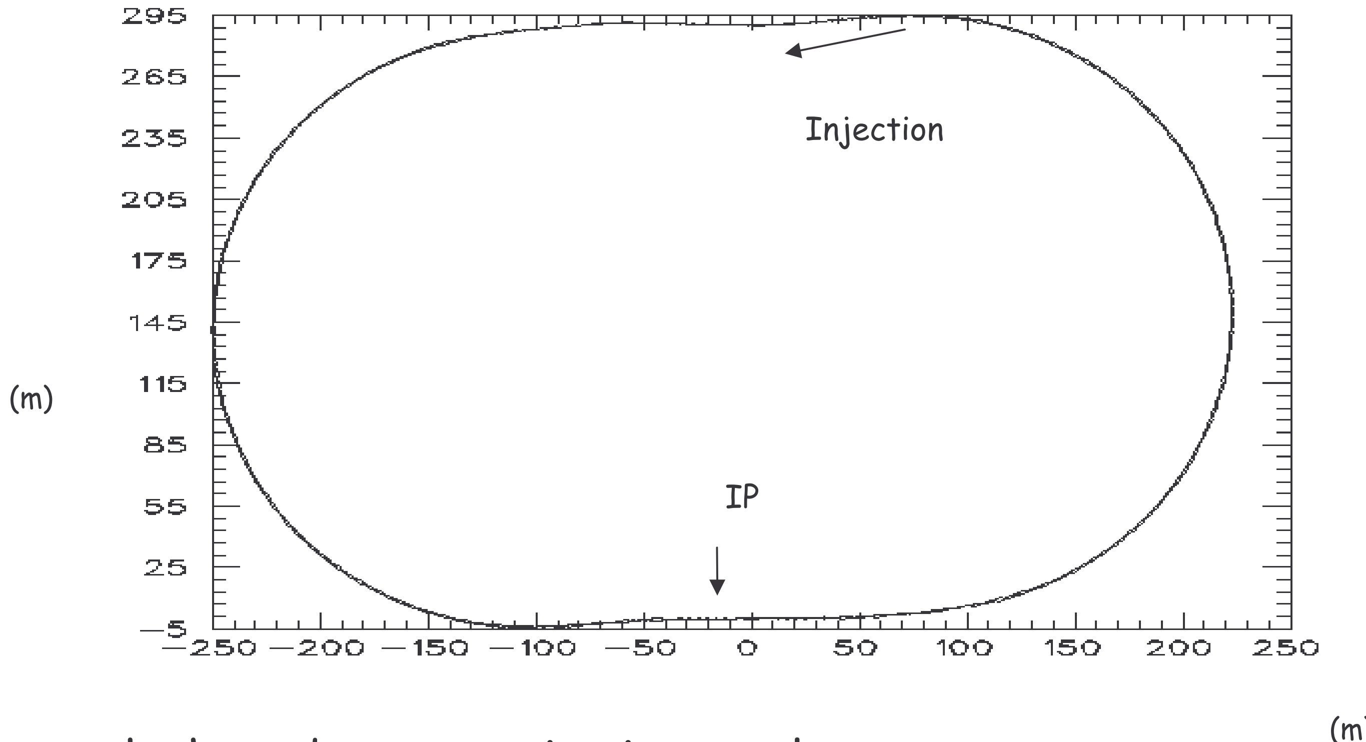
Fixed energy ring – no ramping

- -Most stable operation
- -Fixed energy allows injection of prepolarized electrons – P>70%
  (no ramping induced depolarization)
- -Prepolarized electron injection allows large dipole curvature (ρ = 81 m)
  (radiative polarization not required)
- -Large dipole curvature reduces RF synchrotron load & vacuum chamber heating
- -Fixed energy allows "top-up" operation
- -Top up maintains maximum (optimal) current
- -Top up allows shorter lifetime & therefore higher luminosity
  (higher beam-beam tune shift permitted)

But … self polarization of positrons still required – 22 min. at 10 GeV

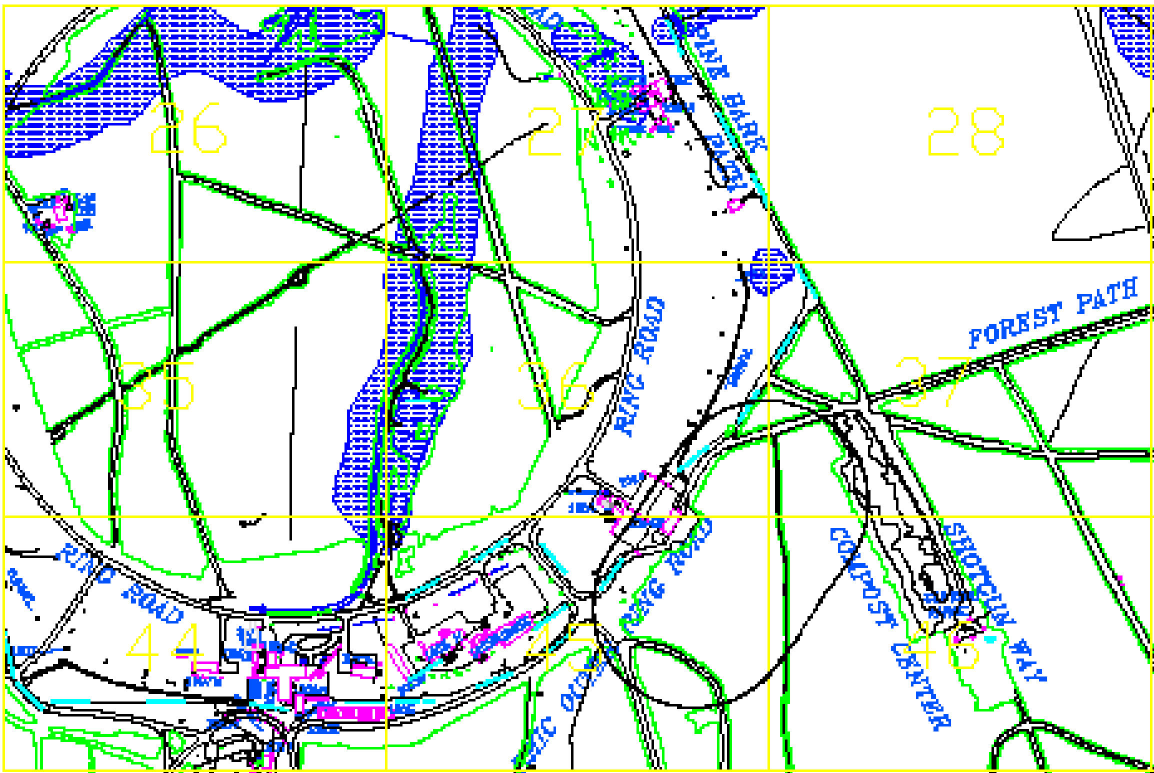
But … fixed energy ring requires expensive 10 GeV injector

Electron/Positron Ring



- Race track shaped storage ring in one plane
- Vertical polarization in arcs – spin rotators for long. pol. at Interaction Point
- Polarized electron injection from 5-10 GeV
- Unpolarized positron injection from 5-10 GeV
- Self polarization of positrons at 10 GeV – τ_p = 20 minutes

Electron/Positron Ring at 4:00 (?)



Design Drivers/Considerations

		Reason	Concerns & Measures
Beam emittance (uncoupled x, nm)	40-60 (10 GeV) 50-90 (5 GeV)	Match ion beam	Arc lattice Wiggler superbend
Beam y/x emittance ratio	~0.2	High luminosity	70% polarization High P_{eq} HERA update
Damping decrement	Damping time < ~25 ms at 5GeV?	Less beam-beam limit reduction at low E	Wiggler || superbend for low E operations
Bunch intensity **(120 bunches)**	1×10^{11} (0.45A)	High luminosity	Vacuum chamber (syn. radiation), RF, instability …
Injection	On energy injection: top-off or continuous	Integrated luminosity Shorter Lifetime accomodated	On energy Injection, flexible bunch-bunch filling.
Beam-beam tune shift limit	$\xi_y \sim 0.08$	B-factory achieved	Working point near integer(spin), study

Luminosity Considerations

F. Wang

$$L = \frac{\pi}{r_e r_i} F_c \gamma_e \gamma_i \xi_i \xi_e \sigma'_{i,x} \sigma'_{e,x} k_e \frac{(1+k)^2}{k^2}$$

Fc is the collision frequency

ξ the beam-beam tune shift

ke = εe,y/εe,x is the electron beam emittance ratio

k=σy/σx is the beam aspect ratio at IP.

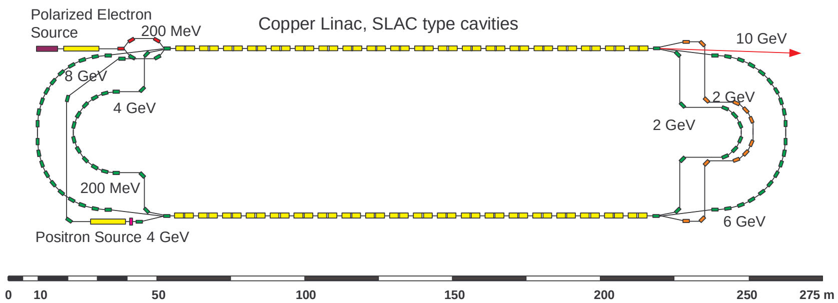
σ' is the beam angular amplitude at IP.

- Round Beams would be preferable for maximum luminosity.
  - à Comparable balanced beam-beam tune shifts (x,y)
- But problematic for polarization
- Bates Siberian Snake is an example of a possible local emittance xformer
- Flat Beams Adopted for the baseline ZDR

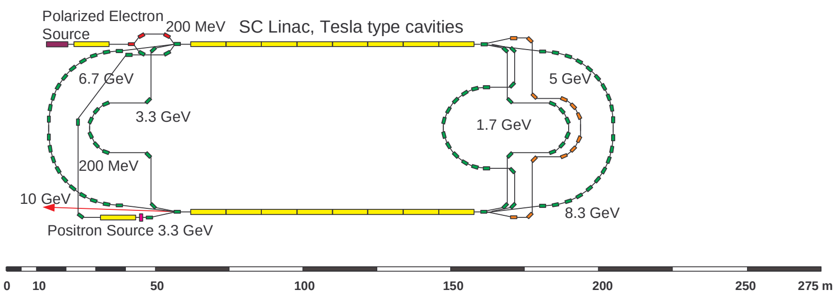
10 GeV Accelerator Options

J.v.d.Laan

- Several variants appear viable
- Injector is expensive, but will not limit eRHIC physics performance



Recirculating NC linac



Recirculating SC linac

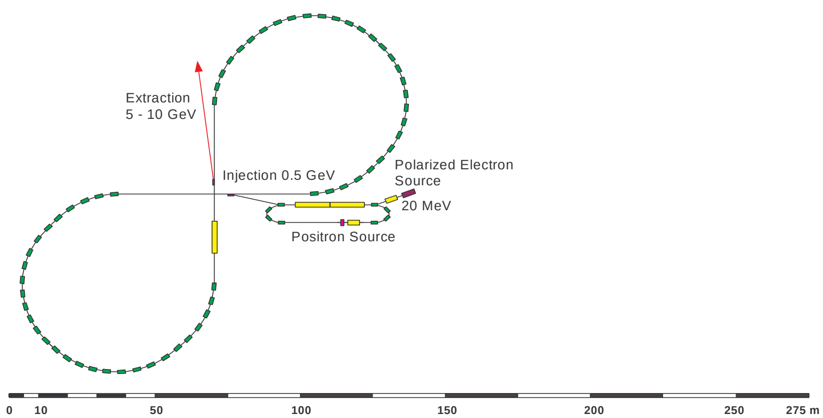
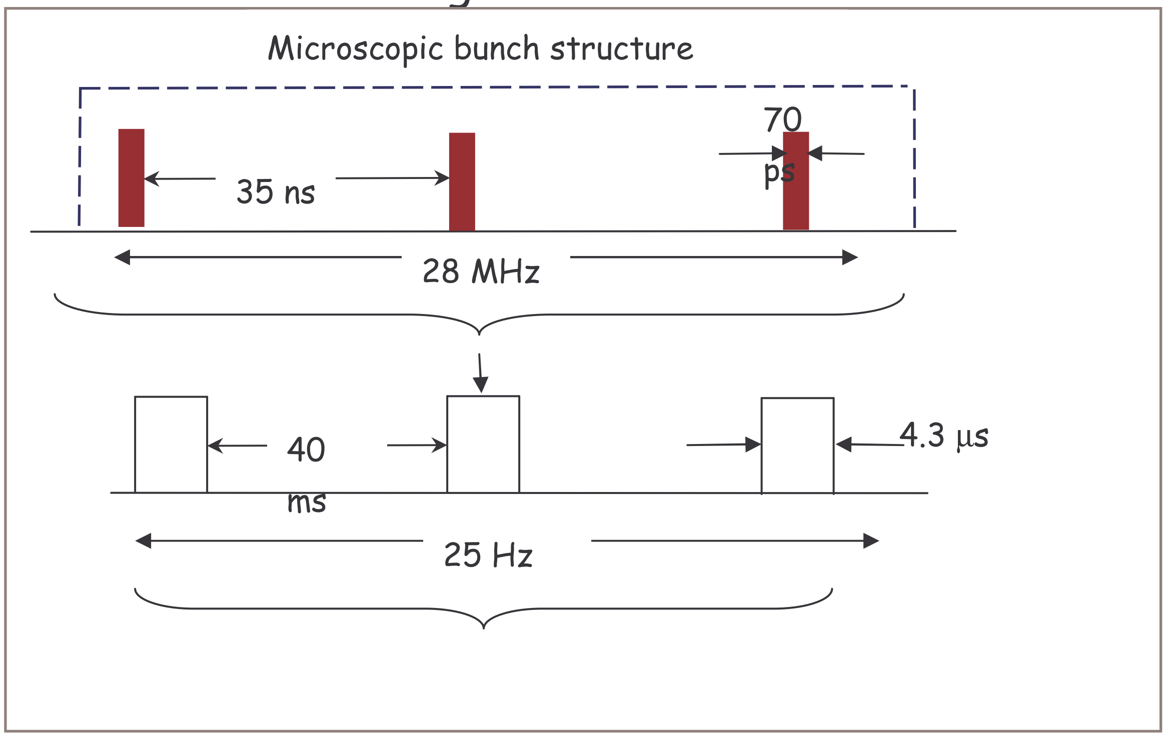


Figure 8 booster synchrotron

Polarized Photoinjector

M. Farkhondeh

•Stack many pulse trains (15000) of 1.3 pC bunches at 25 Hz rates over 10 minutes to fill electron ring.

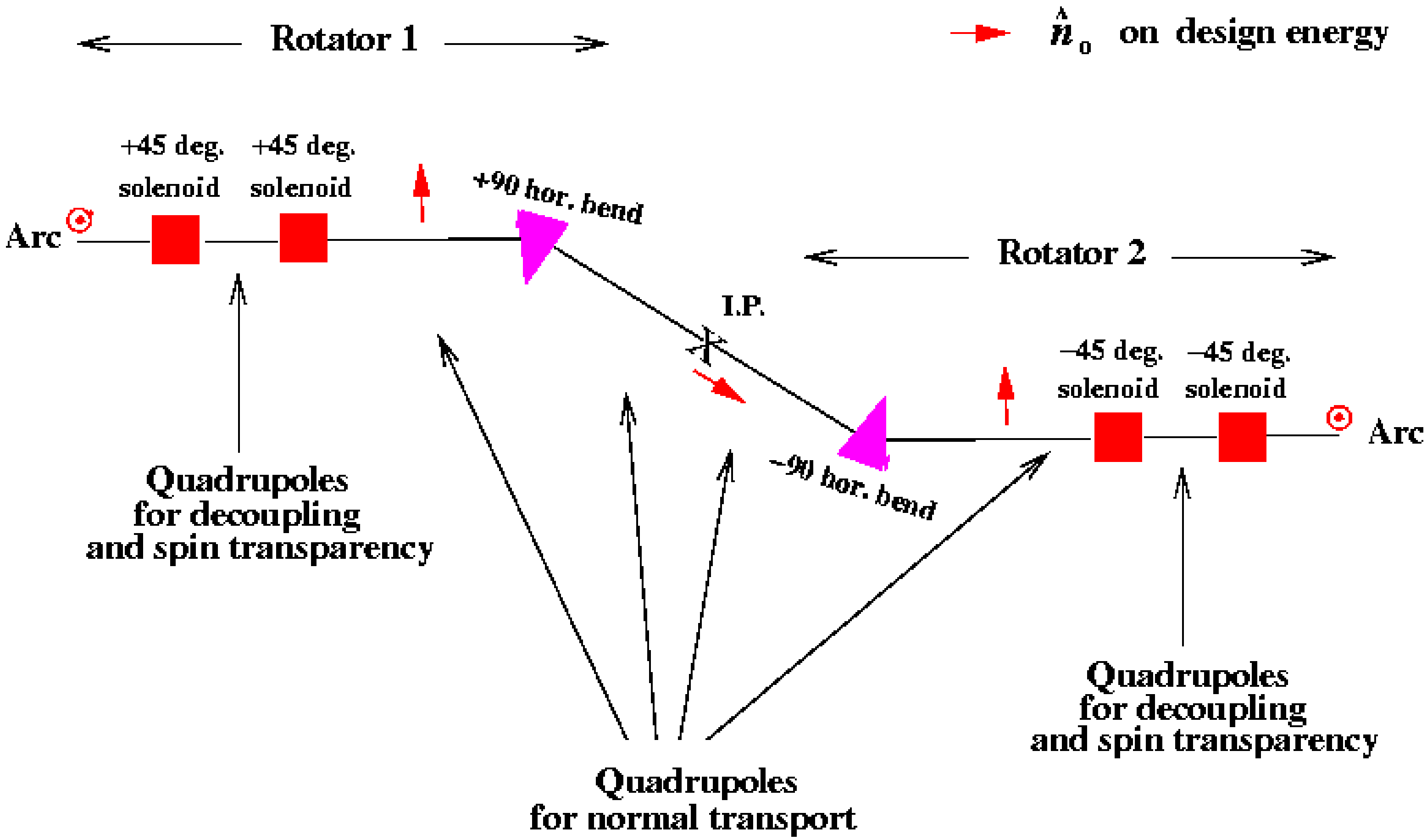


•Similar peak requirements as JLAB's G0 experiment, 40 uA, but very low macroscopic duty factor and average currents.

•Bates has excellent infrastructure and expertise to develop this source.

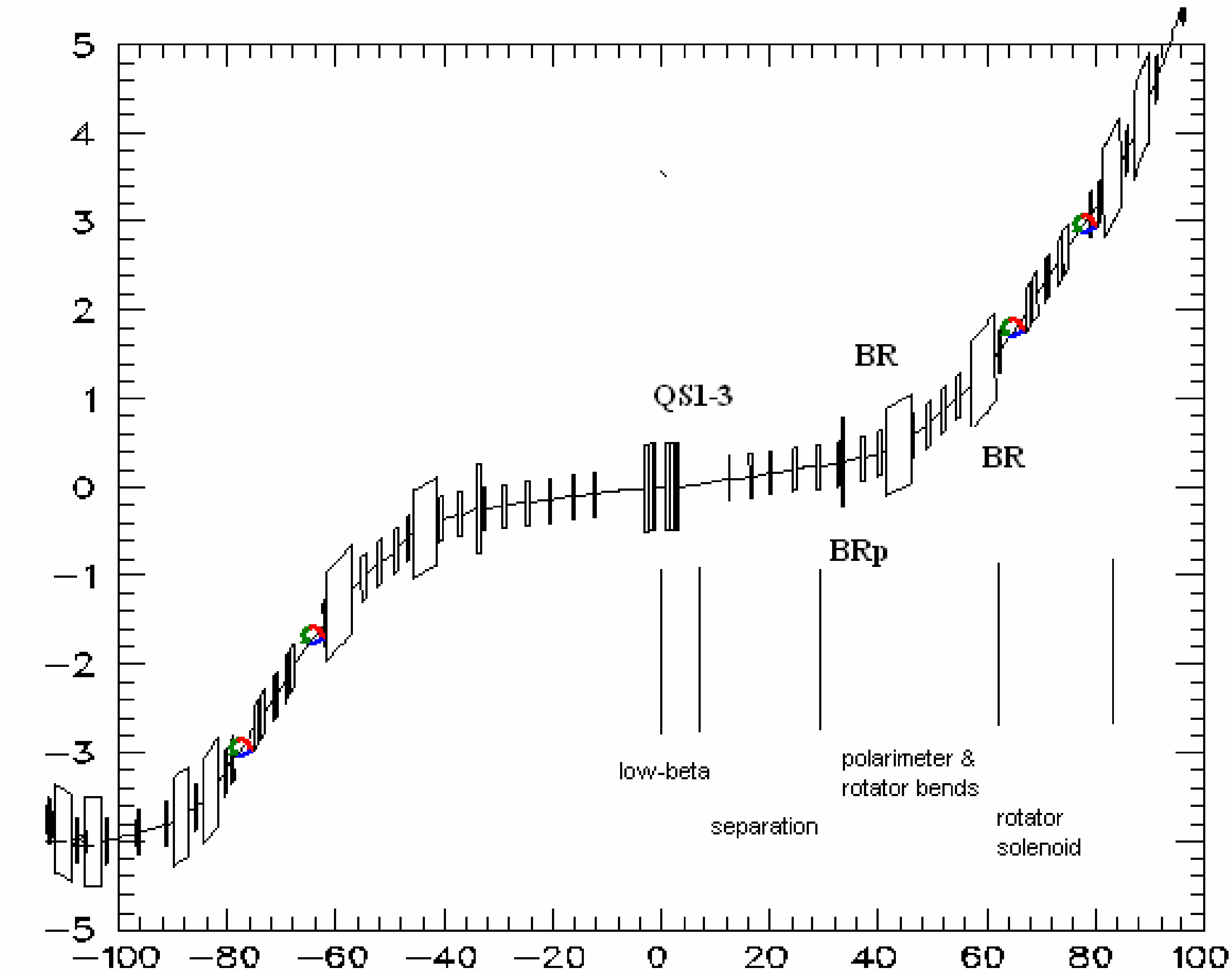
Solenoidal Spin Rotator

D.P.Barber, Y.M.Shatunov



- No vertical bends
- Pure P longitudinal only at 8.5 GeV

e-ring IR straight layout: (lattice ZDR2.0)



Polarization Simulations

Spin matching:

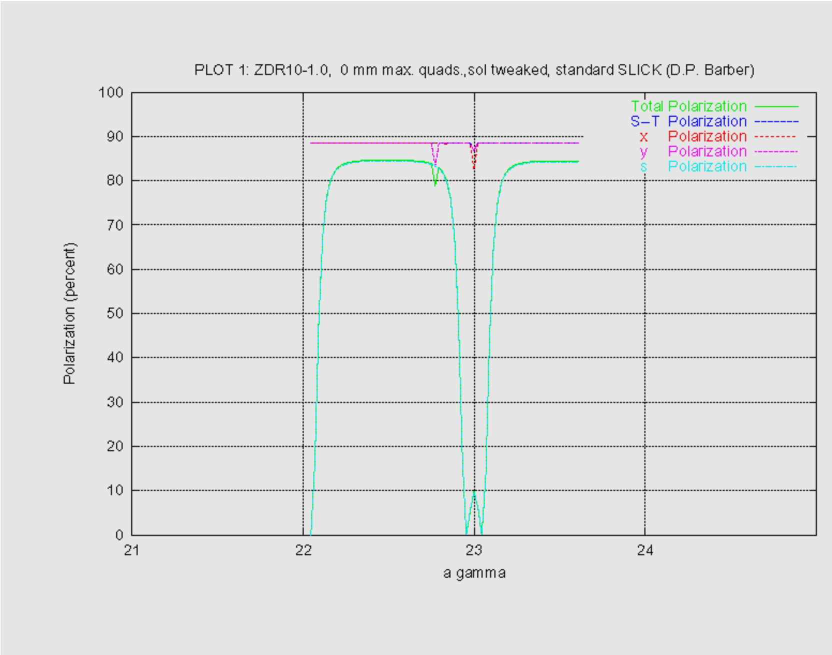
solenoid in rotator: locally spin-transparent

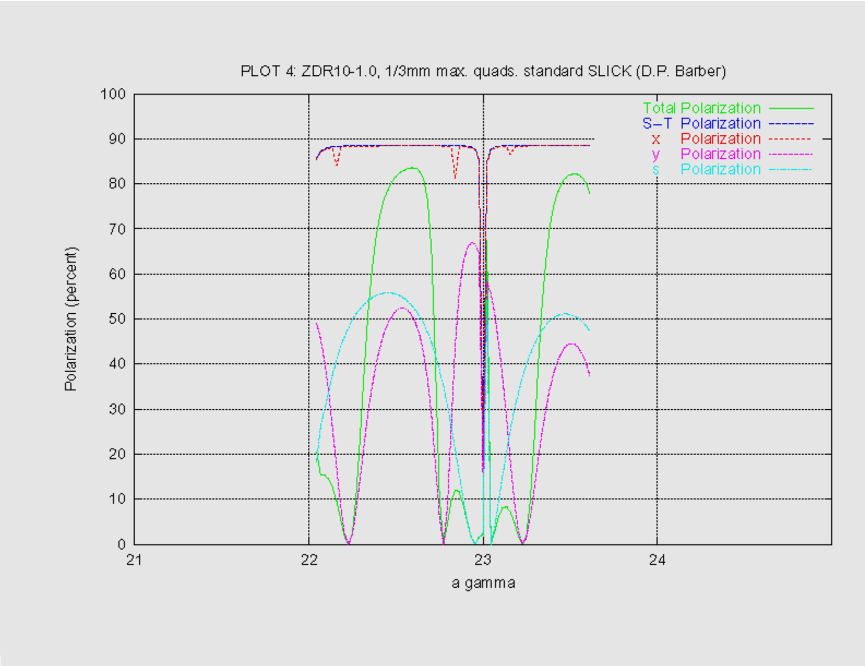
whole IR: spin-synchro term mainly.

SLICK simulation with lattice: (D. Barber) , first results, more to come.

sensitive to orbit errors, not a surprise.

with good corrections, polarization is quite decent with 0.3mm rms COD





Compton Polarimetry

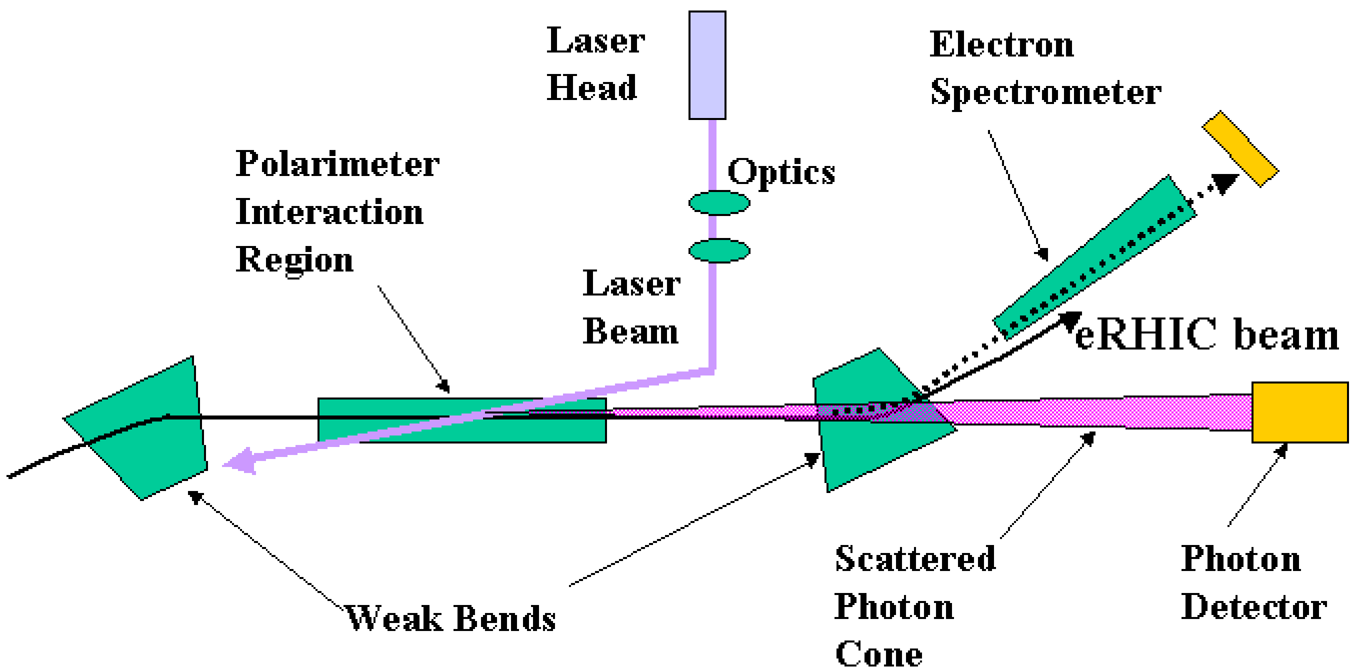
W.A.Franklin

• Compton scattering cross section is well known theoretically and has a term dependent on electron spin and laser helicity

> Can extract e^- polarization by measuring asymmetries in scattering rates for circularly polarized laser light

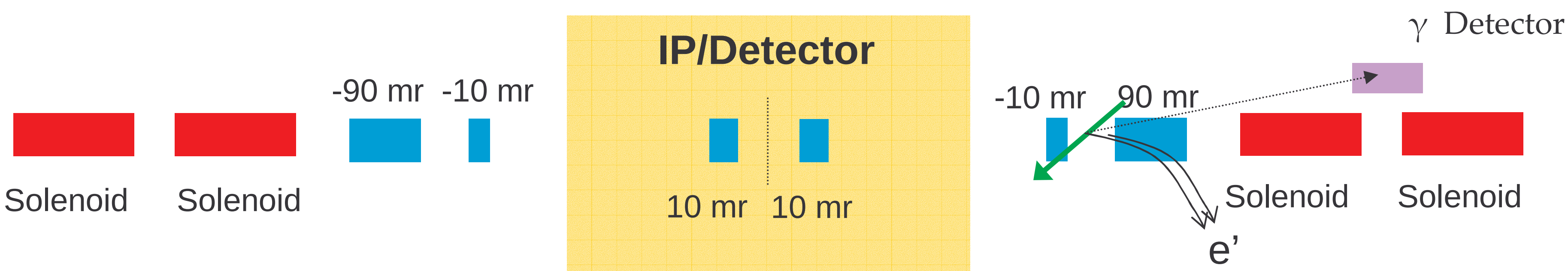
• Compton scattering in highly relativistic frame compresses angular distribution into a narrow kinematic cone and shifts photon frequencies into gamma regime

> Detect backscattered photons or scattered electrons with compact detector



Longitudinal Polarimeter Location

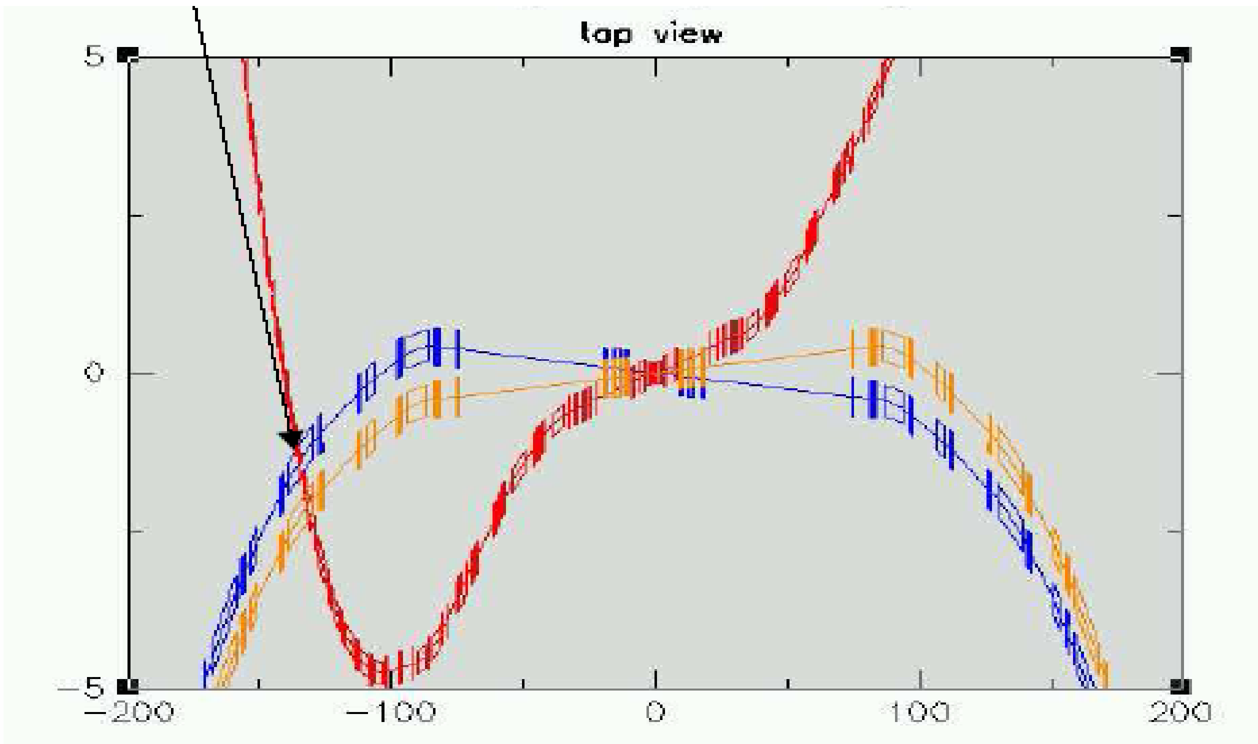
• Locate longitudinal polarimeter between spin rotators and downstream of electron-ion interaction point



- Weak bend upstream of polarimeter compensates for spin precession due to detector's magnetic field
- Limit Compton scattering interaction region to short straight section (5 m) to reduce sensitivity to bremsstrahlung background
- Strong bend downstream of Compton interaction region provides sweep magnet for photon line cledarance and momentum analysis for scattered electrons

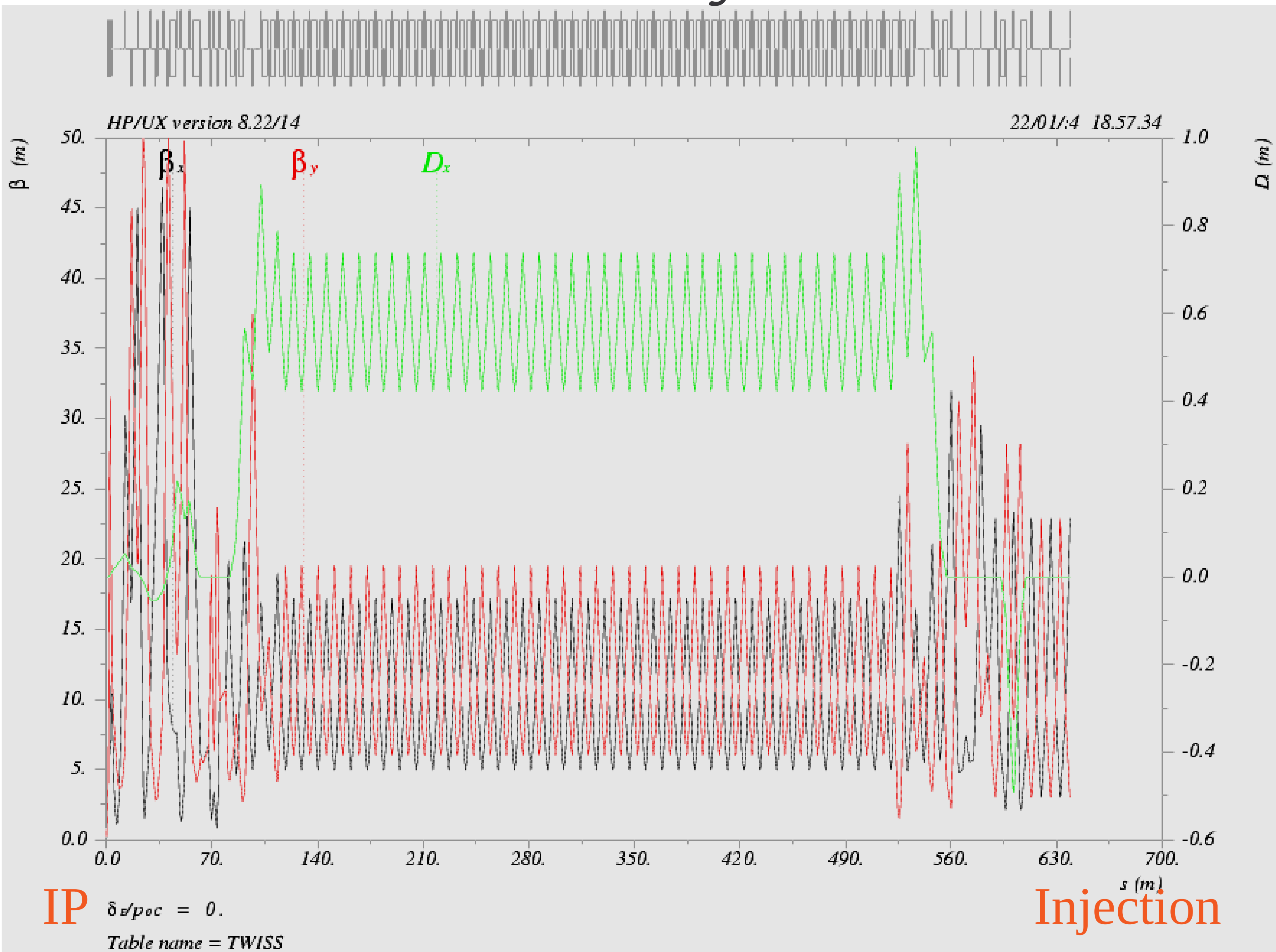
IR Region

"Second Crossing Problem"



Lepton Ring Half Lattice

D. Wang



Variable Emittance for Optimum Luminosity

F. Wang

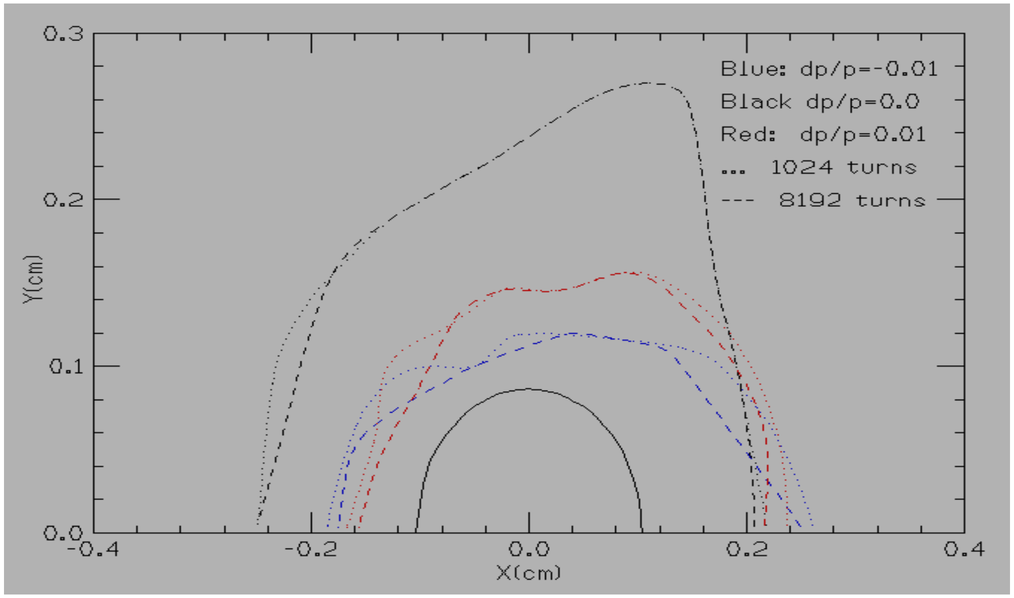
Ke= $\varepsilon_{e,y}/\varepsilon_{e,x}$	$\varepsilon_{e,x}$ (nm.rad)	$\beta_{e,x}{}^*$ (m)	$\beta_{e,y}{}^*$ (m)	Protons ($1e^{11}$) per bunch	ξx	ξy	L 1e32 ($cm^{-2}s^{-1}$)
0.1	54	0.19	0.47	0.57	0.016	0.08	2.5
0.15	54	0.19	0.31	0.85	0.024	0.08	3.8
0.18	54	0.19	0.26	1.0	0.029	0.08	4.5
0.20	54	0.19	0.23	1.13	0.032	0.08	5.0
0.25	54	0.19	0.19	1.41	0.04	0.08	6.3
0.30	45	0.23	0.19	1.41	0.048	0.08	6.3
0.5	27	0.38	0.19	1.41	0.08	0.08	6.3

Lowest emittance substantially larger than 3rd generation light sources

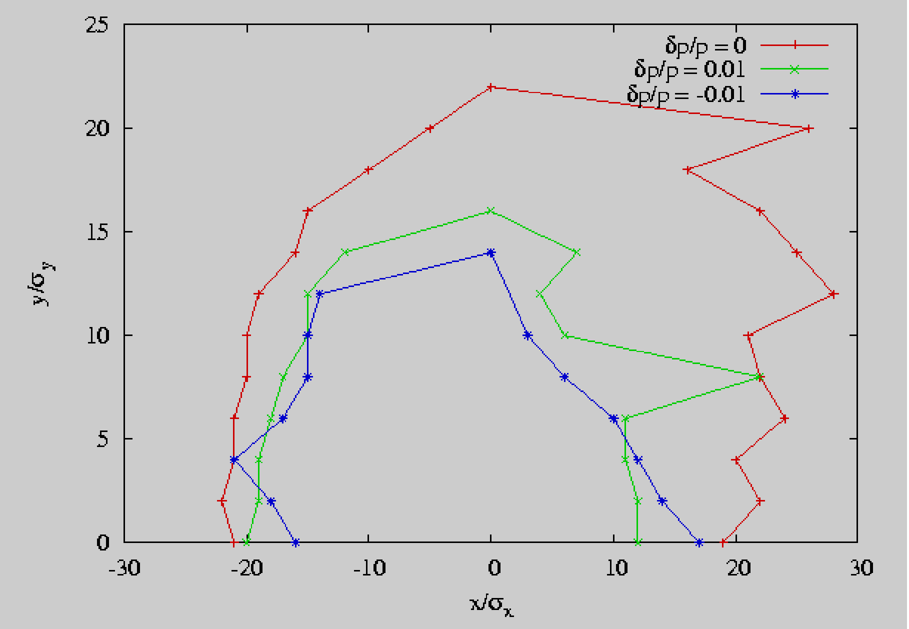
Dynamic Aperture

F. Wang, D. Wang, A. V.Otboyev

Goal of 10σ in both momentum and transverse phase space in the presence of alignment and magnetic errors and colliding beam conditions.



LEGO (Beam size at IP)



SAD (Normalized Beam Size)

Also - Acceptance Issues for Positron Injection

e-Ring Path length adjustment

C.Tschalaer, B. Weng, S.Peggs

Proton Energy	Proton bunch spacing in time (ns)	Colliding frequency (MHz)	Electron ring RF frequency (MHz)	Electron bunch spacing (m)	Electron beam path length (m)	Electron beam path length changes (m)
25	35.5471	28.1317	478.238	10.6568	1278.812	0.8919
50	35.5283	28.1465	478.491	10.6511	1278.136	0.2161
100	35.5237	28.1503	478.554	10.6497	1277.967	0.0473
250	35.5223	28.1513	478.572	10.6493	1277.920	0.0

Possible Solutions : Need engineering evaluation !

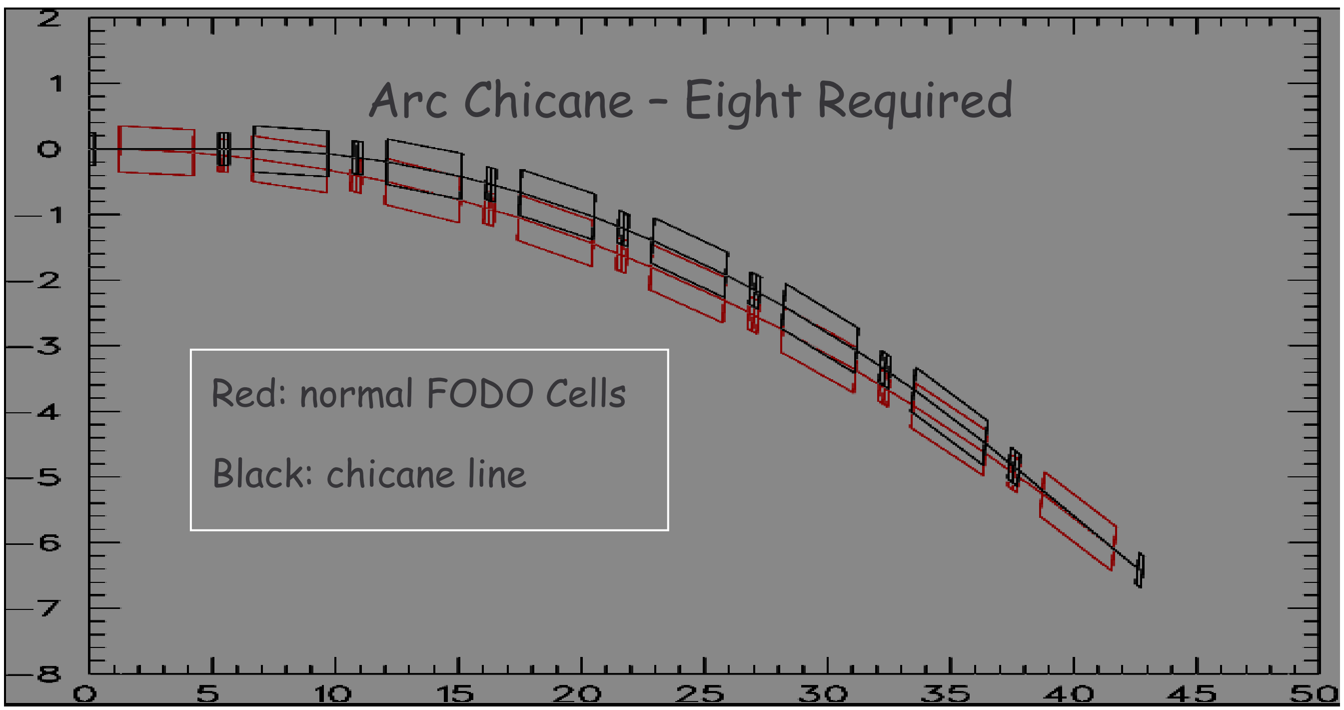
- Magnet chicanes in the arc
- Shift 180^0 arc : No impact on optics, one knob adjustment.

Variable Path Length for e-/e+

C. Tschalaer, B. Weng, S.Peggs, F. Wang

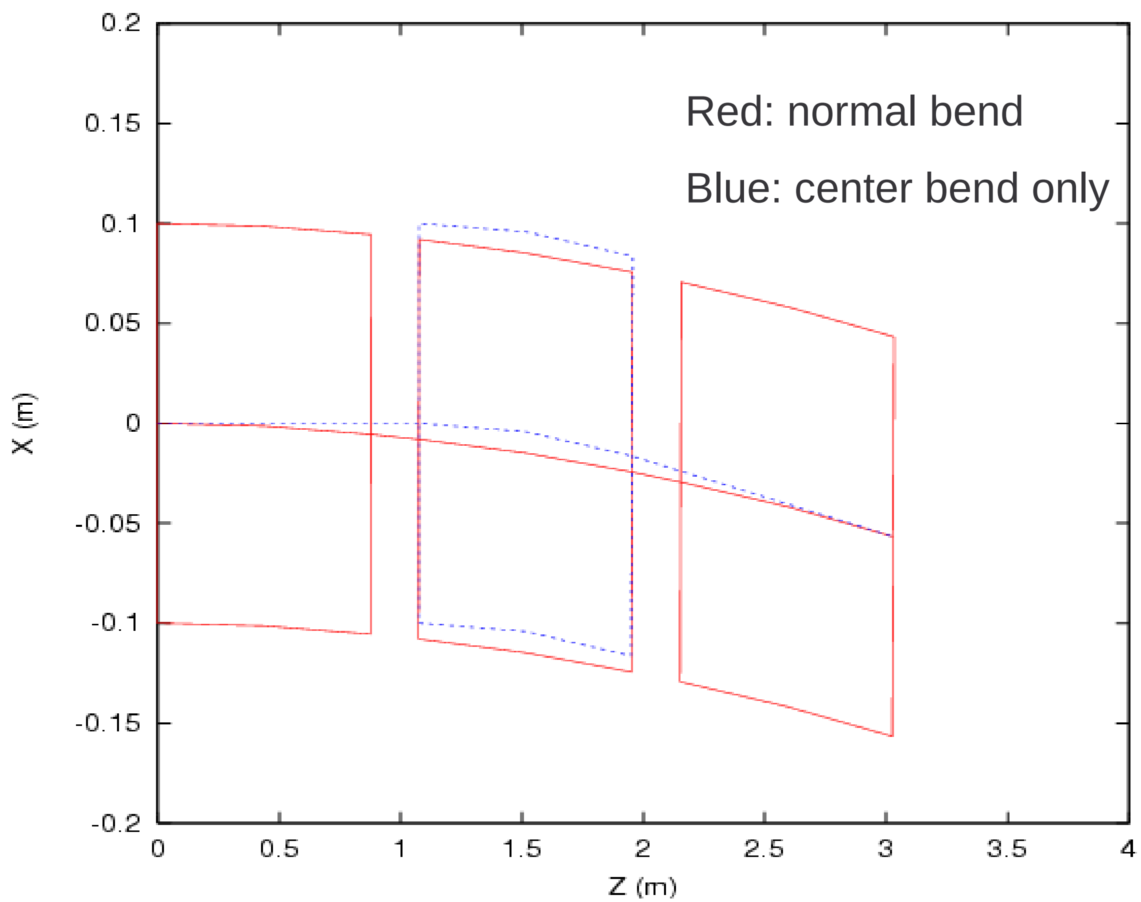
•The proton (heavy ion) velocity (energy) determines the collider frequency and consequently the electron path length. ΔL_{max} = 89 cm

•A minimum proton energy of 50 GeV (rather than 25 GeV) reduces ΔL_{max} to 22 cm



•Other schemes are possible – but this is an unsolved/uncosted item

Scratch of a "super-bend" for radiation enhancement at 5 GeV



	All bends on	Center bend on only
ρ (m)	70.3m	23.4
P (MW)	~0.35	~1.06
τ_x (msec)	~54.5	~18.1

ξ^{∞}_{y} reduction ~ 20%

(Compare to 10 GeV)

*Total path length increase: ~4.48cm.
* Linear rad. power at 10 GeV ~14kW/m

e-ring path length adj. requirement (with super-bends)

Beam Instabilities

D. Wang

- Conventional instabilities (impedance-driven)
  - single bunch front: comparable to BF's now
  - multi-bunch front: relatively easier than BF's

eRHIC lepton ring :

needs to deal with both e- and e+ beams

Other instabilities

Fast Beam-Ion Instability (FBII, for e-)

Electron Cloud Effects (ECE, for e+)

Comparable to B-factories

Intensity Parameters: Not Extreme

10^{11} Particle/bunch(	**eRHIC lepton ring**	PEP-II LER/HER	KEKB LER/HER	CESR-III
Energy(GeV)	**5 ~ 10**	3.1/9.0	3.5/8.0	5.3
Circumference(m)	**1278**	2200	3016	776
RF freq.(MHz)	**478.6 or 506.6**	476	508	500
RF voltage(MV)	**5~25**	6/15	10/18	3
Total current(A)	**0.45**	2.4/1.4	1.9/1.2	1.0
Particle/bunch(1e11)	**1.0**	1.0/0.6	0.9/0.7	2.0
Bunch spacing(m)	**10.6**	1.9	2.4	2.4
Energy loss/turn(MeV)	**0.72/11.7**	1.2/3.6	1.6/3.5	1.0
Average beta(m)	**~15**	~17	~10	~20
Bunch length(cm)	**1~2**	1.0	0.4	1.5

Single bunch parameters of BF and CESR: in routine operation, not the limits.

Bottom up costs estimates

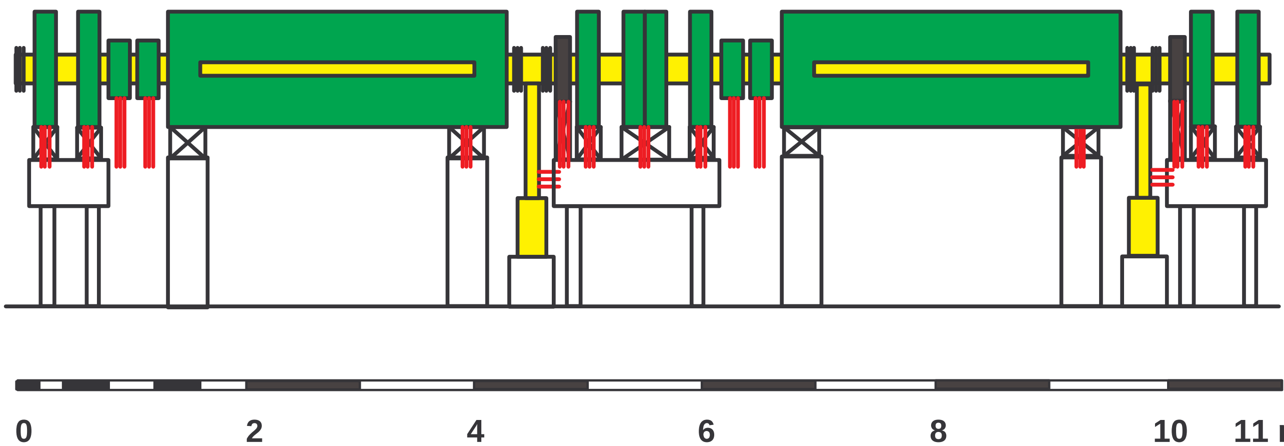
J.v.d.Laan

Quads | Dipoles | Orbit Correctors | Sextupoles

NEGs | Bellows | Getter / Ion pumps

Flip Target / Wire Scanner / BPM | Ion Clearers

Supports | Controls



- Assembling "notebook" of quotations/component costs
- Costs as delivered to the laboratory – no installation

Costs:
59 k$/m

Systems Costs Estimates: Main Ring

Storage Ring			
	Tunnel		13.9
	Magnets (incl. measurements)		53.2
	Support/Stands		2.5
	Vacuum		21.5
	Power conversion		8.5
	RF		13.7
	Feedback (transv. + long.)		3.7
	Diagnostics		3.1
	Control System		8.0
	Subtotal Ring		***128.1***
Interaction Region			
	Magnets		4.5
	Power conversion		1.8
	Support/Stands		0.6
	Vacuum		1.6
	Diagnostics		0.6
	Subtotal Interaction Region		***9.1***
Total Ring			**137.2**

Top Down Cost Estimates

Top down scaling from construction of other accelerators

- Swiss Light Source Booster
- Swiss Light Source
- Argonne Booster
- Bates SHR
- JLAB
- TESLA

	eRHIC
•10 GeV Main Ring	\$150 - \$200 M
•10 GeV Injector	\$50 – 150 M

Reasonably consistent with bottoms up estimates

Large variability in injector due to choice of injector

Operation of eRHIC Lepton Ring

- Assumption I: >5 Hr Proton/Hadron Lifetime – ½ Hour Fill/Ramp Time
- Assumption II: >5 Hr Lepton Lifetime
- Assumption III: $P_{equilibrium} > 50\%$
- Assumption IV: Stored Lepton Current ~ 1 A
- Assumption V: On Energy Injection

- Scenario I: Top up Lepton Current Every Second

  <1 mA Injector Pulses

  Figure 8 Booster, SC Linac, NC Linac all satisfactory

  Detector Must "Tolerate" Injection

- Scenario II: Top up Lepton Current Every 10 minutes

  10 mA Injector Pulses

  Polarizing Booster, SC Linac, NC Linac all satisfactory

  Detector state can be "safe" (reduced HV) during injection

Possible Parameters for Higher Luminosity

		Electron	Proton	Electron	Au
Energy E	[GeV]	10	250	10	100
$k=\varepsilon y/\varepsilon x$		0.18	1	0.18	1
$K\sigma=\sigma y/\sigma x$		0.43	0.43	0.43	0.43
ε_n (ion)	[πmm mrad]		15.0		6.0
Emittancs εx	[nm.rad]	54.0	9.4	53.0	9.4
Emittancs εy	[nm.rad]	9.7	9.4	9.5	9.4
βx^*	[m]	0.19	1.08	0.19	1.08
βy^*	[m]	0.19	0.2	0.20	0.2
ξx		0.042	0.0095	0.033	0.0095
ξy		0.1	0.0041	0.08	0.0041
Particles/Bunch		1.40E+11	1.41E+11	1.38E+11	1.40E+09
Luminosity £	[$cm^{-2}s^{-1}$]		1.0E+33		9.9E+30

Continuing Activities

-Layout on BNL site

-Interference/clearance w/ RHIC rings

-Path length adjustment for varying ion energies

-Continuing evaluation/simulation of equilibrium polarization due to alignment tolerances and magnetic errors

-Integrate downstream spin rotator w/ longitudinal Compton Polarimeter

-Compare merits of different injector architectures – eRHIC operation

-Positron production, acclereration and capture
e-/e+ ring dynamic aperture

-Develop polarized photoinjector satisfying eRHIC requirements

-Refine cost models for eRHIC accelerator and ring

-Options for Higher luminosity

Summary

eRHIC ZDR now available in hardcopy

Ring – Ring Design ready to proceed to a FDR (First Order Design Report)

Polarization e- > 70% 5-10 GeV

Polarization e+ > 70% (22 minutes at 10 GeV)

Full Longitudinal Pol. at 8.5 GeV

Luminosity 0.44×10^{33} (10 GeV on 250 GeV)

Possible Increase of Lepton Current (~1A) for $L = 10^{33}$

Preliminary Design Review in Summer/Fall 2004 (?)